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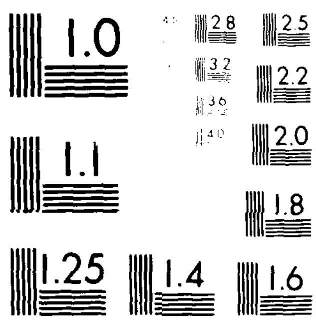

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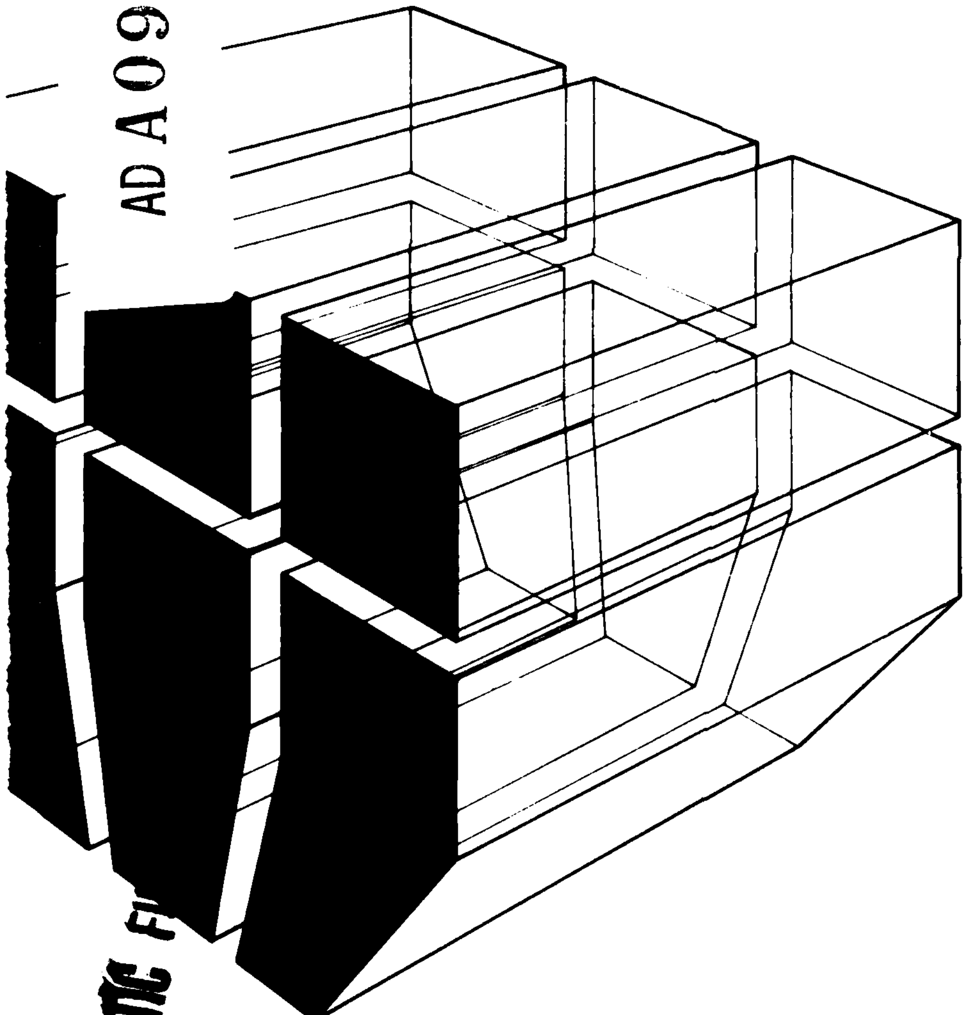
TECHNICAL REPORT E-168
May 1981

WOOD-DERIVED, LOW-BTU GAS AS A SUBSTITUTE FUEL AT RED RIVER ARMY DEPOT



by
C. Mack
A. Collishaw

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This study investigated the feasibility of using wood-derived low-Btu gas as a substitute fuel at Red River Army Depot (RRAD). The investigation reviewed the state of the art of wood gasification, selected candidate boiler plants at RRAD, and evaluated four gasified alternatives. The investigation revealed that the state of the art of wood gasification is still relatively undeveloped, and though air gasifiers are commercially available, further demonstration is necessary to determine reliability.

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An analysis of the four alternatives revealed that alternative IIIB is the most cost-effective gasifier alternative. Alternative IIIB suggests close coupling a gasifier system to boiler plant 1142 and producing a low-Btu gas derived from available dry wood waste. Currently, boiler plant 1142 operates 24 hr/day, 365 days/year, and can produce 31,000 lb of steam/hr (31.7×10^6 J/hr) for process and heating load. This system requires an FY80 capital investment of $946,000, has a 25-year present value (PV) annual savings of $2.35 million, and will replace 67 million cu ft (1.9×10^6 m^3) of natural gas/year. The savings/investment ratio (SIR) of this alternative is 2.48, and has a simple payback of 6.3 years.

FOREWORD

This study was performed by the U.S. Army Construction Engineering Research Laboratory (CERL) for the U.S. Army Materiel Development and Readiness Command. The Energy Showcase Coordination Director of Military Programs was Mr. James C. Stillman. Assistance was provided by Mr. Gary Schulz, Showcase Director, and Mr. John R. Addington, Director for Services, Red River Army Depot.

The CERL principal investigator was Mr. Anslie N. Collishaw and the Associate Investigator was Mr. Curtis Mack, both of CERL's Energy Systems (ES) Division. Mr. R. G. Donaghy is Chief of CERL-ES.

COL Louis J. Circeo is Commander and Director of CERL and Dr. L. R. Shaffer is Technical Director.

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WOOD-DERIVED, LOW-BTU GAS AS A SUBSTITUTE FUEL AT RED RIVER ARMY DEPOT

1 INTRODUCTION

Background

In 1978, the Department of Energy (DOE) and the Department of Defense (DOD) formed a task force to develop showcase energy projects at Army installations. These showcase projects are designed to show industry, Government, and the general public that energy technologies that do not rely on fossil fuels are ready (or nearly ready) for commercial use.[1]

The U.S. Army Construction Engineering Research Laboratory (CERL), as part of this joint DOE/DOD effort, was asked to identify sites at the Red River Army Depot (RRAD) that could be used to demonstrate the conversion of biomass (wood) to a low-Btu gas.

Objective

The objectives of this study were to provide criteria for (1) the design and procurement of a wood gasifier system which could convert biomass to a low-Btu gas at RRAD, and (2) the modification of existing RRAD boilers so they could produce and burn biomass-derived, low-Btu gas.

Approach

1. Information on existing boiler plants and steam production rates at RRAD was obtained. Boiler plants able to use low-Btu gas as a substitute fuel were identified; from this list, two candidate boiler plant systems were recommended to the Director of Services, RRAD. The recommendations were based on the potential impact the showcase energy project would have on RRAD energy consumption.

2. Commercially available wood gasifier systems were evaluated to determine which could meet steam loads at the candidate RRAD boiler plants. This evaluation focused on fixed-bed and fluidized-bed gasifier designs and the use of dry and green wood as fuel stock. Four alternative gasifier systems were developed.

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[1] <u>Army Energy Showcase Project Proposals</u> (Department of the Army, December 1978), p 3.

3. The cost effectiveness of each alternative was determined over a 25-year functional life.

4. Comparative economic analyses were done to determine the most cost-effective gasifier system. Recommendations for that alternative's implementation were then developed.

Scope of Report

This report discusses the technical and economic feasibility of substituting a low-Btu gas at RRAD for a primary fuel such as natural gas. Manufacturers' claims are used only to indicate how the use of gasifier technology at RRAD would affect air and water quality. Environmental impact was considered in an Environmental Assessment prepared by CERL's Environmental Division under a separate study; those results are summarized in Appendix D.

2 STATUS OF COMMERCIAL GASIFICATION SYSTEMS

Wood gasification is a rediscovered technology; it began back in the latter part of the 1800s, when coal, not wood, was the fuel stock and the low-Btu gas that was produced was burned in boilers. However, when oil and natural gas became plentiful around 1920, gasification research stopped. Later, during World War II, gas shortages in Europe revived interest in the process, and research was done on developing portable gasifier units. When oil again became plentiful after the war, interest in gasification receded until the oil embargo of 1973.[2]

Today, many types of gasifiers are being designed, ranging in size from 100,000 Btu/hr to 100 million Btu/hr (105×10^6 to 105×10^9 J/hr) and yielding a gas with an energy content from 90 to 1000 Btu/standard cu ft (3.3 to 37.2×10^6 J/m^3). Data collected from gasifier manufacturers indicate that gasifier unit components are available as "off the shelf" items, ready for installation. When an order of definite specifications is received (i.e., size, output capacity, type, etc.), the units are built off-site. They can then either be connected in parallel with existing units to meet the output requirements of large boilers or they can be turned down to meet boiler load requirements during lower load periods. Since most of these units are still in the development/commercialization stages, and only a few are field-operable, their reliability is unknown.

Gasification Technology

There are four gasification processes: air gasification, oxygen gasification, hydrogasification, and pyrolytic gasification. (A flow diagram of each process is shown in Figure 1.) Air gasification is the simplest form of gasification, in which excess char formed by pyrolysis is burned with a limited amount of air. Air gasifiers appear to be more inexpensive and reliable than the other types. Oxygen gasifiers dramatically increase the energy content of the gas by using oxygen instead of air, but require an oxygen plant or nearby source of oxygen in order to operate. Hydrogasification and pyrolysis gasification are still in the research stage and are not ready for commercial use.

Various air-blown gasifier configurations are commercially available (Figure 2). These configurations can be classified into two groups based on the way wood moves through the unit:

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[2] B. C. Horsfield, "History and Potential of Air Gasification," RETROFIT '79: Proceedings of a Workshop on Air Gasification, SERI/TP49-183 (Solar Energy Research Institute, 1979), p 4-1.

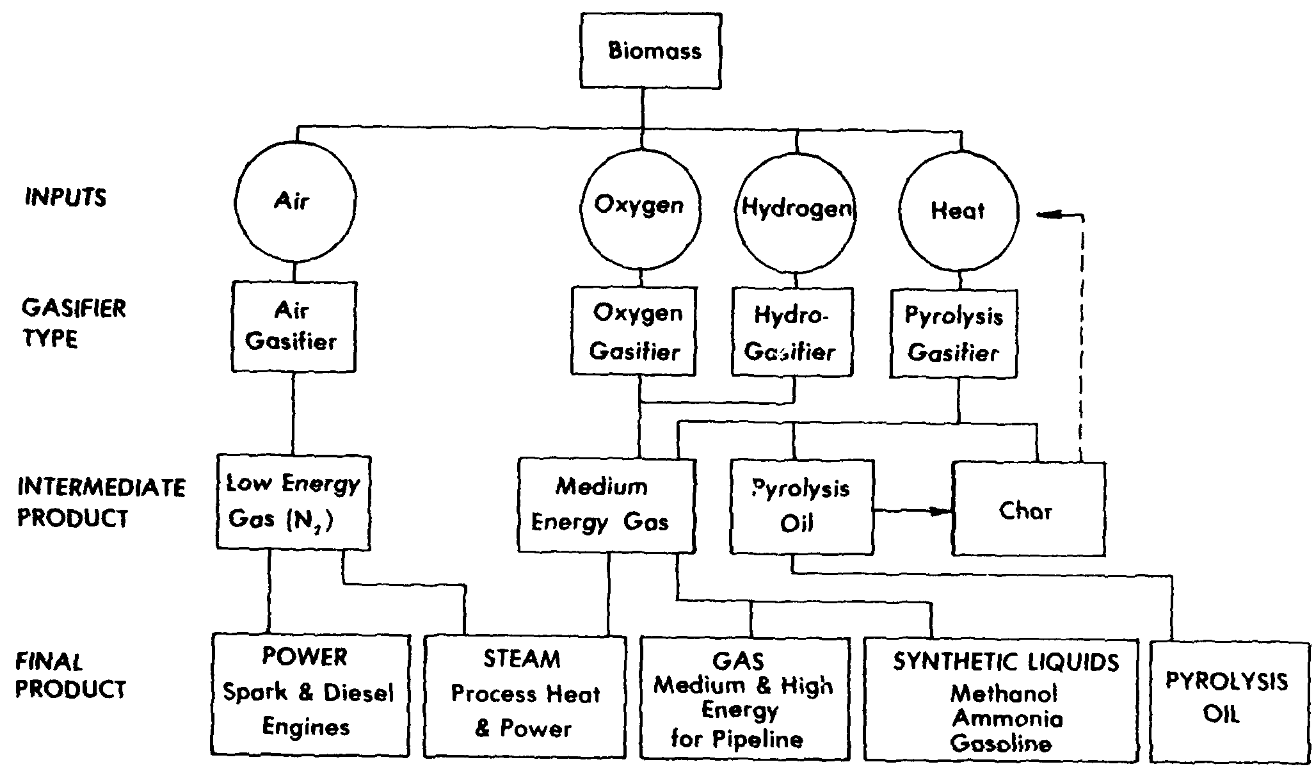

Figure 1. Gasification processes. (From A Survey of Biomass Gasification, SERI/TR-33-239 [Solar Energy Research Institute, July 1979].)

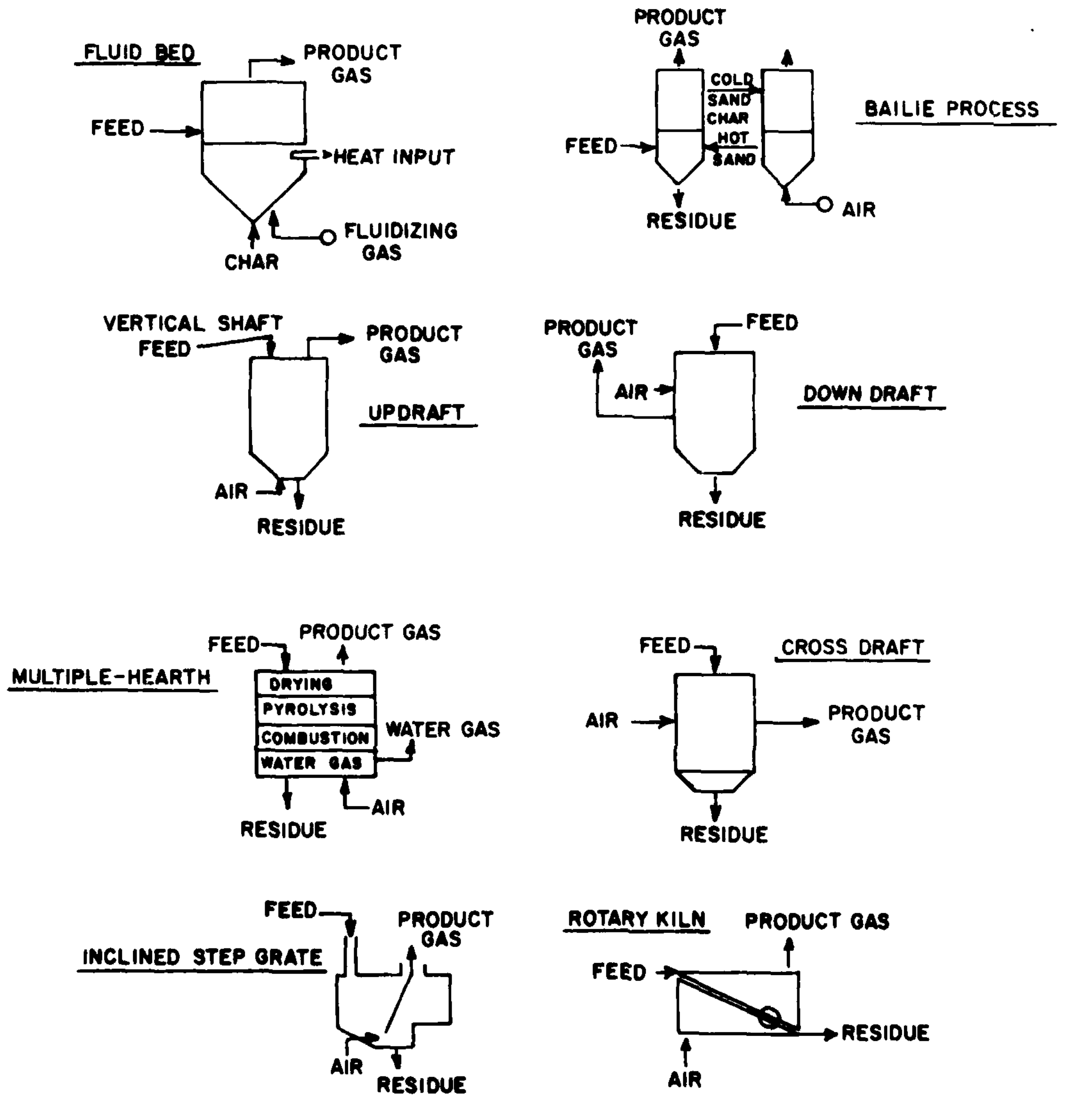

Figure 2. Basic configurations of available biomass gasification reactors. (From A. Collishaw, Appendix B of Technologies for Energy From Biomass by Direct Combustion, Gasification, and Liquefaction, Technical Report E-172 [U.S. Army Construction Engineering Research Laboratory, April 1981].)

1. The fixed-bed configuration is subclassified into updraft, downdraft, and cross-draft. These subclassifications identify the direction from which air is introduced into the reduction zone of the unit.

2. The fluidized-bed configuration uses air or oxygen and steam to fluidize the particles within the unit.

This report will only consider updraft, downdraft, cross-draft, and fluidized-bed designs of the air-blown gasifier. Appendix C lists names and addresses of gasifier manufacturers and research organizations.

Types of Air Gasifiers

Figure 3 is a schematic of an updraft gasifier. In this particular unit, solid fuel is fed into the top of the unit. As the fuel descends, it is dried, reduced, and oxidized. This design offers great versatility in the nature of the fuel that can be used. For example, the unit will accept fuel with varied moisture content levels as high as 50 percent. This unit produces a hot gas with a large percentage of tars and oils which condense out when the gas is cooled. This is not a problem if the fuel is going to be burned close to the gasifier, but if it is to be piped a considerable distance, the gas will cool and the tars and oils will condense, gradually plugging the pipe.

The downdraft configuration (Figure 4) differs from the updraft unit in that air flows downward through the reduction zone and oxidation takes place before reduction. Tars and oils that pass through the oxidation zone are combusted and cracked. This produces a cleaner, low-Btu gas. However, the nature of the fuel that the unit can process is limited by its design. The downdraft design requires a fuel that is fairly uniform in size and has a consistent and low moisture content. If the produced gas is to be piped a considerable distance, the gas will have to be cleaned and cooled before piping.

Cross-draft gasifier units are the simplest of all designs, but are usually limited to relatively small sizes. These particular units were once used on motor vehicles powered by tar-free fuels like charcoal or coal.[3]

The fluidized-bed gasifier has a fluid bed of sand and char suspended by a fast-flowing stream of air. When fuel is introduced to the bed surface, its contact with the hot sand and char causes it to undergo rapid pyrolysis. Wood is completely converted to gas very quickly, taking minutes instead of the hours required of other gasifier designs. This rapid burn rate makes the fluidized-bed gasifier very responsive to load changes in the system; it can handle varied fuels with moisture contents as high as 50 percent.

[3] B. C. Horsfield, "History and Potential of Air Gasification," RETROFIT '79: Proceedings of a Workshop on Air Gasification, SERI/TP49-183 (Solar Energy Research Institute, 1979), p 4-1.

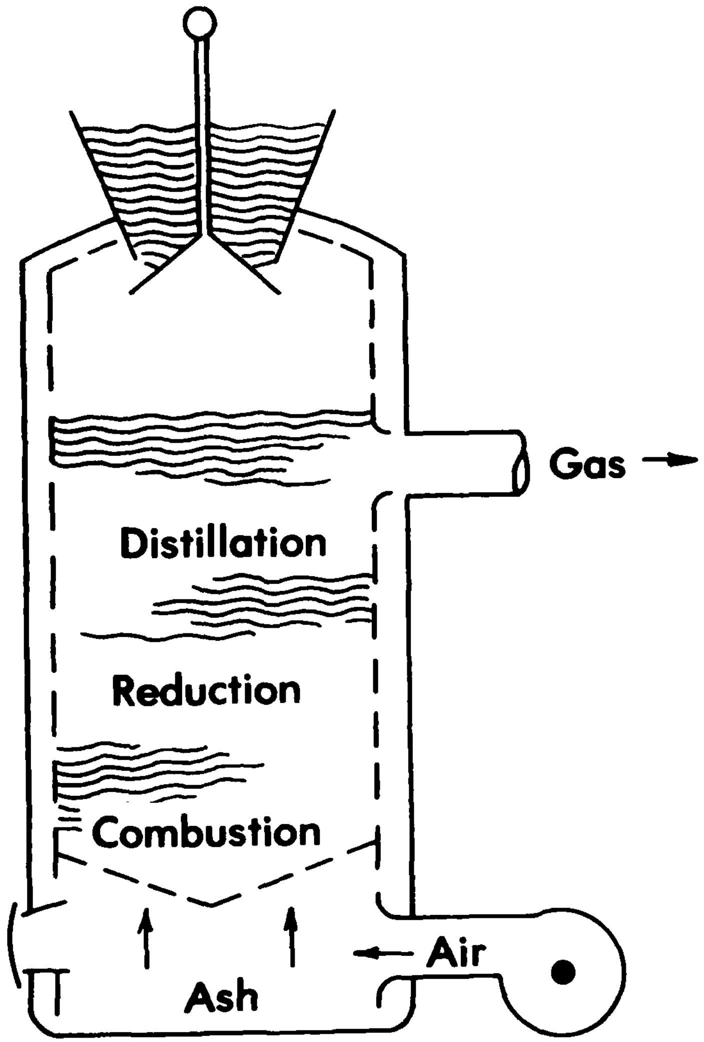

Figure 3. Schematic diagram of updraft gasifier. (From A Survey of Biomass Gasification, SERI/TR-33-239 [Solar Energy Research Institute, July 1979].)

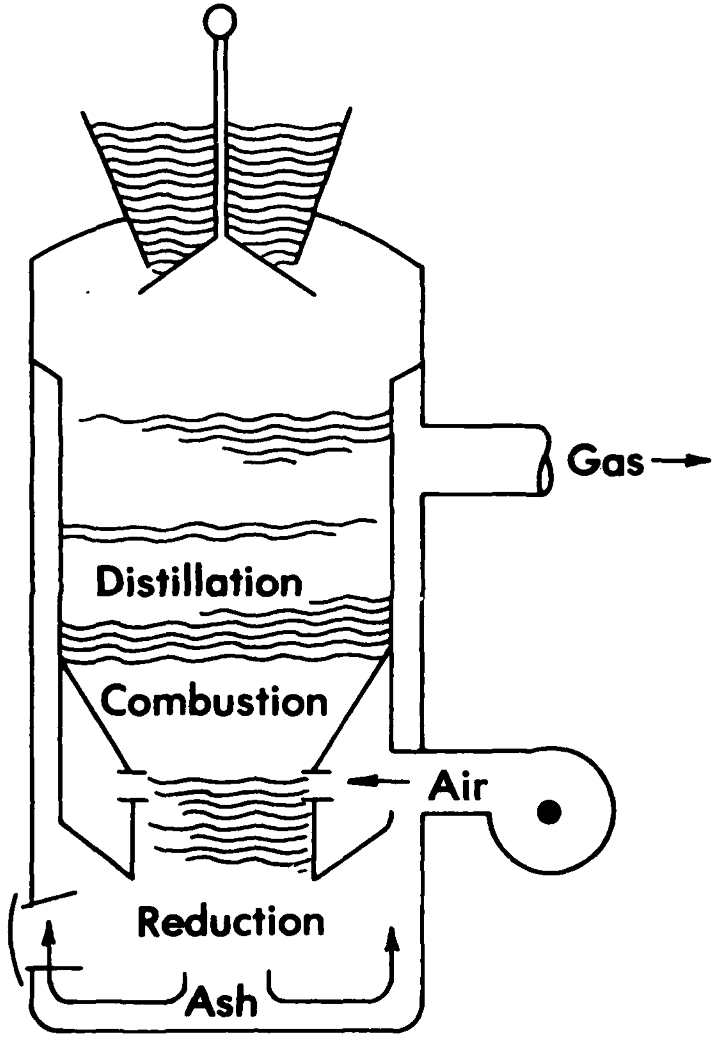

Figure 4. Schematic diagram of downdraft gasifier. (From A Survey of Biomass Gasification, SERI/TR-33-239 [Solar Energy Research Institute, July 1979].)

During the piping of low-Btu gas to a boiler, tars, oils, and hydrocarbons can condense out of the gas as it cools and cause serious disposal problems. Methods of controlling this disposal problem are (1) heat-tracing the gas line above 200^{o}F (93^{o}C) to prevent condensation, or (2) using a down-draft gasifier to greatly reduce the amount of tars and oils in the low-Btu gas, and then burning the tars and oils in the gasifier unit.

3 SELECTION AND DEVELOPMENT OF DEMONSTRATION SITES

Requirements

The sites selected for alternative fuel technology demonstrations at RRAD had to be (1) accessible to the public, and (2) show a substantial replacement of natural gas.

Five RRAD boiler plants were considered; two met all the demonstration site requirements. Figure 5 shows the location of each of the five boiler plants initially considered.

Analysis

Boiler plants 112, 186, 319, 596, and 1142 were chosen for preliminary investigation as demonstration sites. Boiler plant 319 is scheduled to be converted to a wood/coal direct-fired plant in the future. Substituting low-Btu gas for its present fuel would save coal, but no natural gas would be replaced. For this reason, boiler plant 319 was dropped from further consideration.

Substituting low-Btu gas as the fuel at boiler plant 1142 would replace about 15 percent of the natural gas consumed annually at RRAD. Although boiler plant 1142 is in a restricted area (i.e., visitors are not permitted), a system could be devised to pipe low-Btu gas from an unrestricted area to a restricted area. However, the literature and manufacturers agree that if low-Btu gas is piped a great distance, the gas must either be cooled and cleaned to prevent the condensation of tars and oils or the gas line heat-traced to keep the gases hot.

Boiler plants 112, 186, and 596 are all in unrestricted areas, thus allowing visitor access. About 1 percent of the natural gas consumed at RRAD could be replaced by each of these alternatives. And because boiler plants 112 and 186 are near each other and have a combined low-Btu gas output potential, they could also be attached to the gasifier by pipeline.

Boiler 596 was not considered since boiler plants 1142, 112, and 186 had greater natural gas replacement potential.

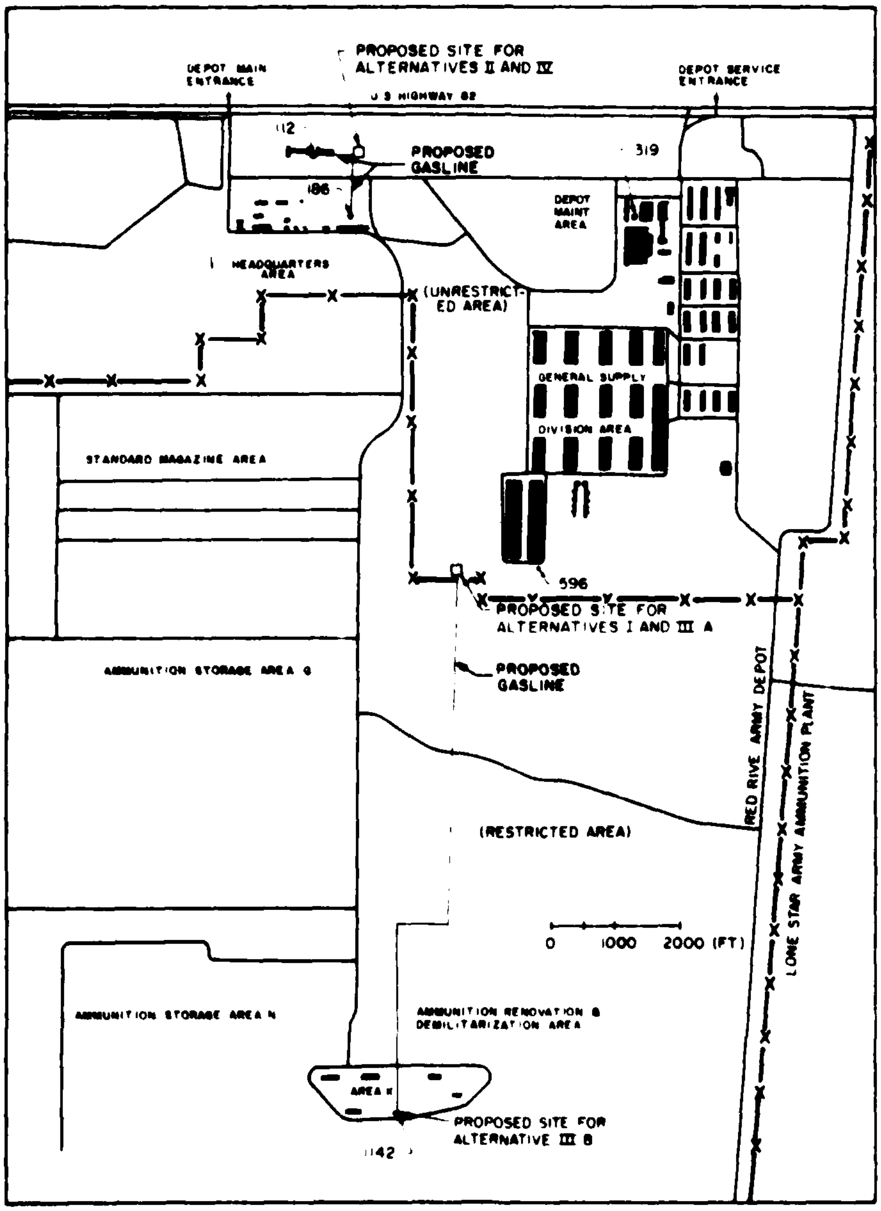

Figure 5. Red River Army Depot and proposed alternative locations.

Candidate Boiler Plant 1142

Boiler plant 1142 is in area K at RRAD, the ammunition renovation and demilitarization area. This is a restricted zone, not accessible to visitors (Figure 5). Boiler plant 1142 supplies process steam to buildings in the area 24 hr/day, 365 days/year. During the winter months (November through March), boiler plant 1142 also supplies steam heat. The plant has a 31,000 lb of steam/hr (31.7×10^6 J/hr) output capacity, which represents 272×10^9 Btu/year (287×10^{12} J/year).

Utilities personnel keep a daily record of the plant's steam output; Table 1 lists its monthly steam production data during calendar year (CY) 79. The amount of steam produced is about the same as 50×10^9 Btu/year (53×10^{12} J/year) output, or 67×10^9 Btu/year (71×10^{12} J/year) input (based on 75 percent boiler efficiency). The actual output is 18 percent of the plant's capacity.

Table 1

Steam Production Data for Boiler Plant 1142, CY79
(Steam Production -- Million lb/Month [$\times 10^{12}$ J/Month])

January	4.3 (4.5)
February	3.2 (3.4)
March	3.0 (3.2)
April	2.8 (3.0)
May	2.9 (3.1)
June	2.8 (3.0)
July	4.1 (4.3)
August	5.3 (5.6)
September	5.0 (5.3)
October	5.4 (5.7)
November	5.2 (5.5)
December	5.5 (5.8)
Total CY79	49.5 = 50,000 MBtu/year (52.2×10^{12} J/year)

Candidate Boiler Plants 112 and 186

Boiler plant 112 is 1500 ft (460 m) northwest of boiler plant 186 (Figure 5). Boiler plant 112 operates 12 months/year. The occupancy schedules are 168 hr/week during summer (March through September), and 45 hr/week for the remaining months. Boiler plant 112 has a boiler output rated at 3700 lb of steam/hr (3.9×10^9 J/hr).

Boiler plant 186 has a rated output of 4440 lb of steam/hr (4.7×10^9 J/hr). The plant provides domestic heat during winter months and humidity control for data processing 12 months/year, 168 hr/week.

Boiler plants 112 and 186 have a combined output capacity of 8140 lb of steam/hr (8590×10^9 J/hr). This represents a 71.3×10^9 Btu/year (75.3×10^{12} J/year) maximum output potential. Assuming that boiler plants 112 and 186 have an operational profile similar to boiler plant 1142 and an actual output of 18 percent of boiler plant capacity, then boiler plants 112 and 186 have an estimated output of 13×10^9 Btu/year (14×10^{12} J/year) or 17.2×10^9 Btu/year (18.2×10^{12} J/year) input (based on 75 percent boiler efficiency). Utilities personnel do not keep steam records for boiler plants 112 and 186.

4 DEVELOPMENT OF GASIFIER ALTERNATIVES

Requirements

Four alternative gasifier systems were considered for use at the demonstration sites at RRAD. Each alternative was analyzed against criteria based on available technology, capital investment, and a savings to investment ratio (SIR). Alternatives I and III would supply low-Btu gas to boiler plant 1142; Alternatives II and IV would supply low-Btu gas to boiler plants 112 and 186. Alternatives I and II would use green wood residue as fuel stock, while Alternatives III and IV would use dry waste wood.

Green wood residue is the leftover residue of forest logging operations. The wood would have to be collected, chipped, and delivered to a gasifier storage area. This would be done by Government personnel or by paying a commercial logger to deliver chipped green wood residue.

Dry waste wood is industrial wood waste. This fuel is now available at RRAD. The wood would be shredded by an existing shredder and delivered to the gasifier location.

The green wood residue and the dry wood waste available for wood gasification will also satisfy the fuel requirements of the FY80 Military Construction wood/coal boiler plant project. If there is not enough wood available for both projects, RRAD personnel will have to choose which project should receive the wood. In making this decision, RRAD personnel should consider that wood used at the wood/coal boiler plant will replace coal, thought to be a plentiful fuel, while wood used in the gasifier will replace gas, a scarce fuel that Army policy has designated for replacement.

Table 2 briefly describes each gasifier alternative.

Table 2

Description of Gasifier Alternatives

Alternative	Boiler Plant Served	Fuel Stock
I	1142	Green wood residue
II	112 and 186	Green wood residue
III	1142	Dry wood waste
IV	112 and 186	Dry wood waste

Alternative I

Process Flow

Figure 6 shows the process flow for Alternative I. Green wood residue, the fuel stock for the gasifier, will be obtained from toppings, branches, and refuse left in the RRAD's forest. The wood residue will be chipped in the forest, trucked to the gasifier location, weighed on a truck scale, and stored in silos nearby. The storage facilities will hold about 500 tons (450 tonnes), enough to meet the need for 72 hours of continuous operation. A manually operated bucket elevator will transfer the chips from the truck to storage, and an automatic feeder system will transfer chips from storage to the gasifier. The wood chips will be fed automatically into the gasifier, which will operate in response to the loads at the boiler plant. Low-Btu gas from the gasifier unit will be cooled, cleaned, and pumped about 10,000 ft (3050 m) by pipeline to boiler plant 1142 and burned there. Ash will be removed from the gasifier by screw conveyor and stored for disposal. Tars and oils obtained from the cooling and cleaning process will be stored and used to supply fuel for a dryer or burned off as waste.

Equipment and Land

A gasifier unit and a gas cooling, cleaning, and piping system will be needed for Alternative I. (A dryer unit is optional, but has been figured in the cost analysis.) However, the peak and minimum loads recorded at the boiler plant are unreliable, and more accurate records of the steam profile must be kept so manufacturers can calculate the maximum turn-down ratio and the number of gasifier units required for this alternative. The gasifier system selected should be capable of delivering 40 to 50 million Btu/hr (42.2 to 52.8×10^9 J/hr). Dryers, piping systems, and gas cleaning equipment are commercially available. There may be some technical difficulty in piping the gas, but the problem can be resolved with present technology. Auxiliary equipment will include a truck scale; storage facility for fuel and waste; conveyors; augers; electric, water, and sewage lines; instrumentation; controls; and an alarm system. A warehouse building (40 x 40 ft [12 x 12 m]) to house the gasifier, control room, and restroom may be required and is included for economic analysis. Other facilities will include a parking lot and an access road to the gasifier site. The site should require about an acre of land located as closely as possible to boiler plant 1142; this area must be unrestricted and accessible to visitors and RRAD personnel. A possible layout plan and location site for the Alternative I site is shown in Figures 7 and 5, respectively.

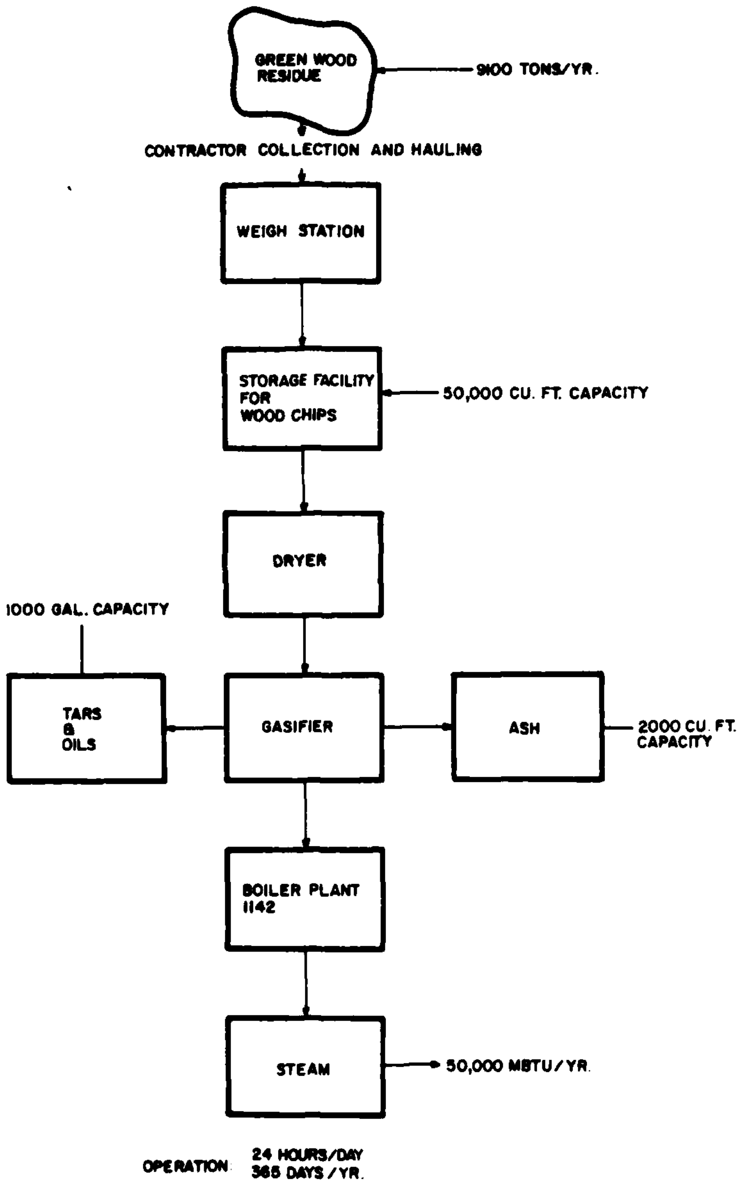

Figure 6. Process flow for Alternative I.

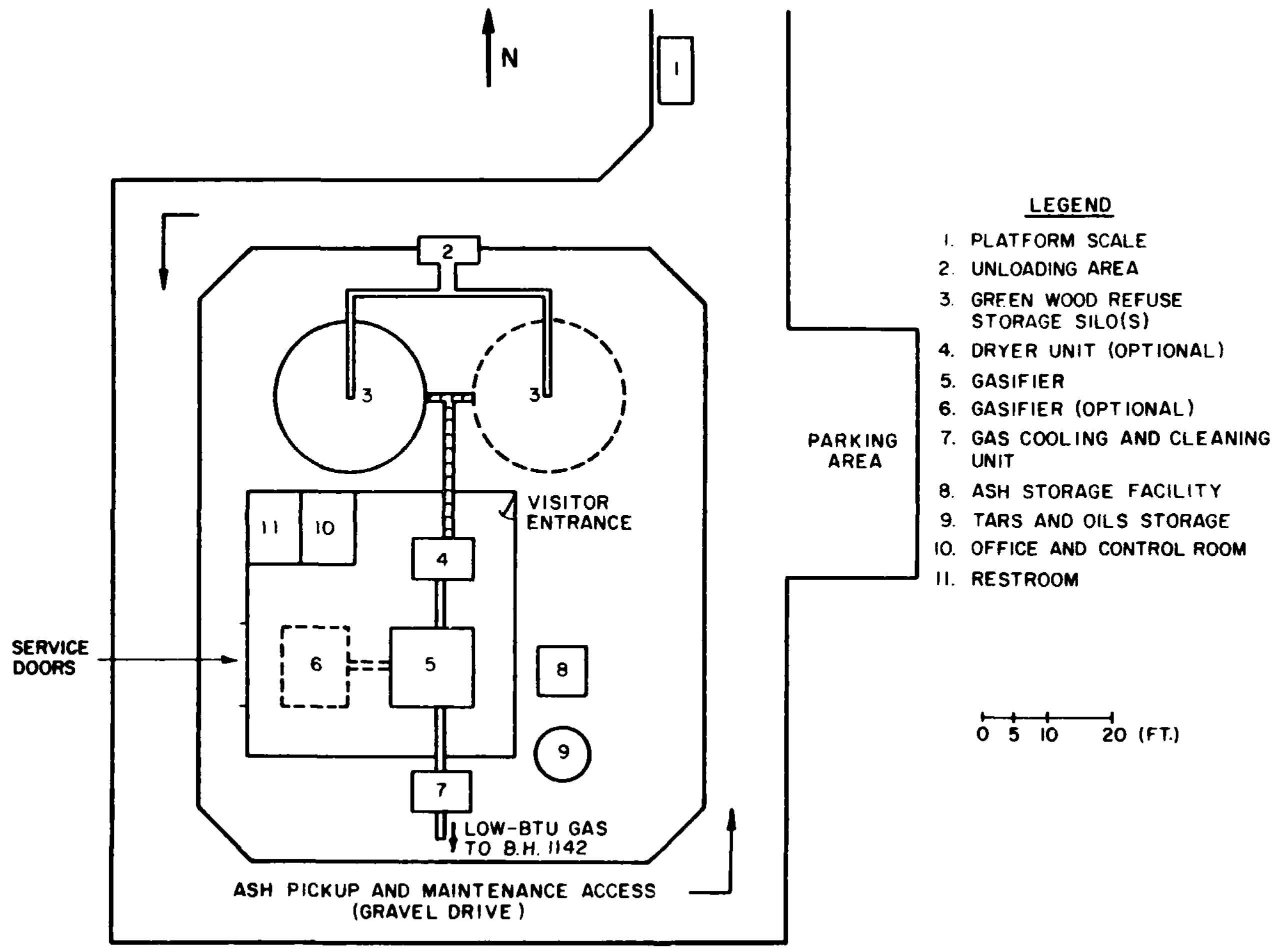

Figure 7. Layout of proposed gasifier site -- Alternative I.

Cost Analysis

The economic analysis for Alternative I is given in Appendix A, Tables A1 and A2; an FY80 investment of about $1.59 million is required. The 25-year present value (PV) saving is about $1.64 million; PV debits total about $1.48 million and PV credits about $3.12 million. This alternative has an SIR of 1.03.

Alternative II

Process Flow

Figure 8 shows the process flow for Alternative II. The fuel stock is the same as for Alternative I. The green wood residue will be chipped and hauled to a weighing station and weighed on RRAD's truck platform. The wood will then be taken to the gasifier site where it will be transferred by bucket elevator to a storage silo. A conveyor system will automatically transfer the wood chips from storage to a surplus hopper above the gasifier; from there, the fuel stock will be fed into the unit automatically. The ash, tars, and oils collected during the process will be disposed of in the same way as described in Alternative I. The low-Btu gas will then be cooled and cleaned. A portion of the gas will be piped about 400 ft (120 m) to boiler plant 112; the rest will be piped about 1200 ft (370 m) to boiler plant 186.

Equipment and Land

This alternative requires gasifier(s), gas cleaning equipment, and gas-line and storage facilities for green wood chips, ash, tars, and oils. However, the size and type of the gasifier system required cannot be determined until the steam output of boiler plants 112 and 186 is established. (A more accurate steam profile is required because manufacturers need peak and minimum loads to calculate turn-down ratios and the number of gasifier units required.) This alternative requires a gasifier system capable of producing 5 to 10 million Btu/hr (5277 to 10 554 J/hr). One or more gasifier units can be hooked together in parallel to produce the amount of gas required. All other required equipment (see the discussion of Alternative I) is technically and commercially available. (A dryer is optional for this alternative, but has been included in the cost analysis.)

Auxiliary equipment will include conveyors; augers; electric, water, and sewage lines; instrumentation; automatic controls; and alarm systems. A warehouse building (30 x 40 ft [9 x 12 m]) to house the gasifier control room and a restroom are optional, but are included for economic purposes. The alarm will be in the main control (building 319) of the boiler plant and will be set to sound should problems occur when no operators are at the gasifier site. The instrumentation required for this alternative is highly technical, since operating two boiler plants with one gasifier system will require

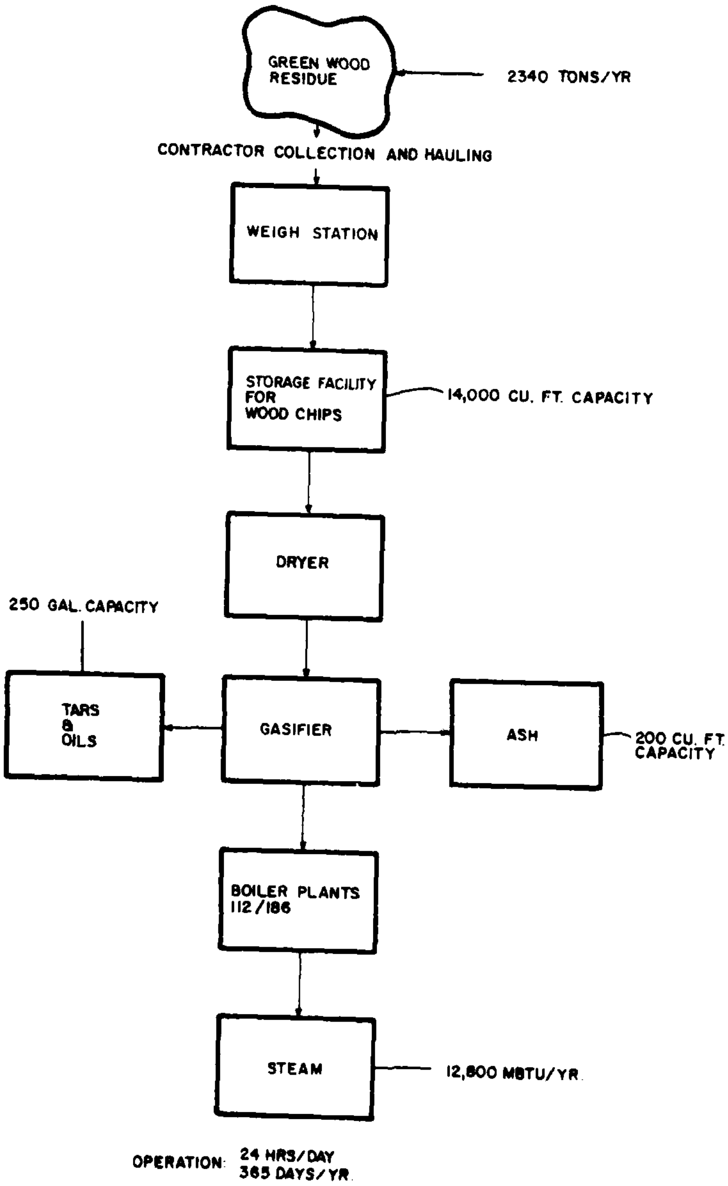

Figure 8. Process flow for Alternative II.

sophisticated controls.[4] Other facilities include a parking lot and an access road.

The site should require about three-quarters of an acre of land midway between boiler plants 112 and 186. Figures 5 and 9 show the possible location and site layout for this alternative, respectively.

Cost Analysis

The economic analysis for Alternative II is given in Appendix A, Tables A3 and A4; an FY80 investment of about $472,000 is required. The 25-year PV savings is about $363,000. The SIR is 0.77.

Alternative III

Alternative III has two variations designated as Alternatives IIIA and IIIB. These alternatives will serve boiler plant 1142 and use dry wood waste as a fuel. The gasifier for Alternative IIIA would be outside the restricted area, would include a gas cleaner, and would pipe cleaned gas 10,000 ft (3000 m) to building 1142. Alternative IIIB, which would be closely coupled to boiler plant 1142, would use an insulated line to pipe uncleaned gas to the boilers. The following description pertains to both Alternatives IIIA and IIIB, except as noted above.

Process Flow

Figure 10 shows the process flow for this alternative. The fuel stock will be dry wood waste (15 percent moisture content) from boxes and pallets shipped to RRAD. A shredder at RRAD will prepare the wood for gasifier use. The shredded material will be transferred to the gasifier site by truck and unloaded onto a bucket elevator. From there it will be transferred to a storage silo. A conveyor system will transfer the wood waste from the silo to a surge hopper above the gasifier via a level control device that will operate in conjunction with a rotary drive feeder. The low-Btu gas produced by the system will be cooled, cleaned, and piped to boiler plant 1142, as described in the discussion of Alternative I. The ashes will be collected, stored, and disposed of in the local landfill used by RRAD. The oils and tars will be burned off in a flare that was constructed with the overall system to prevent explosion.

[4] Personal communication between CERL and Paul Turney, DM International, May 12, 1980.

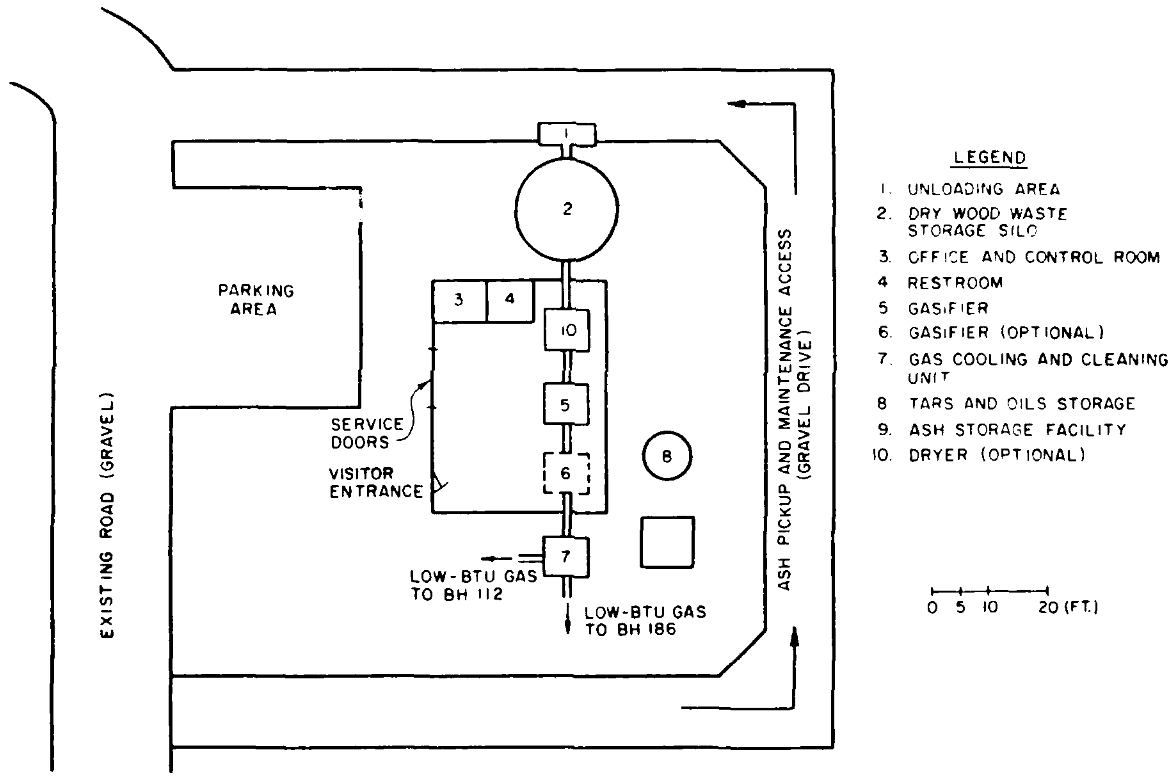

Figure 9. Layout of proposed gasifier site -- Alternative II.

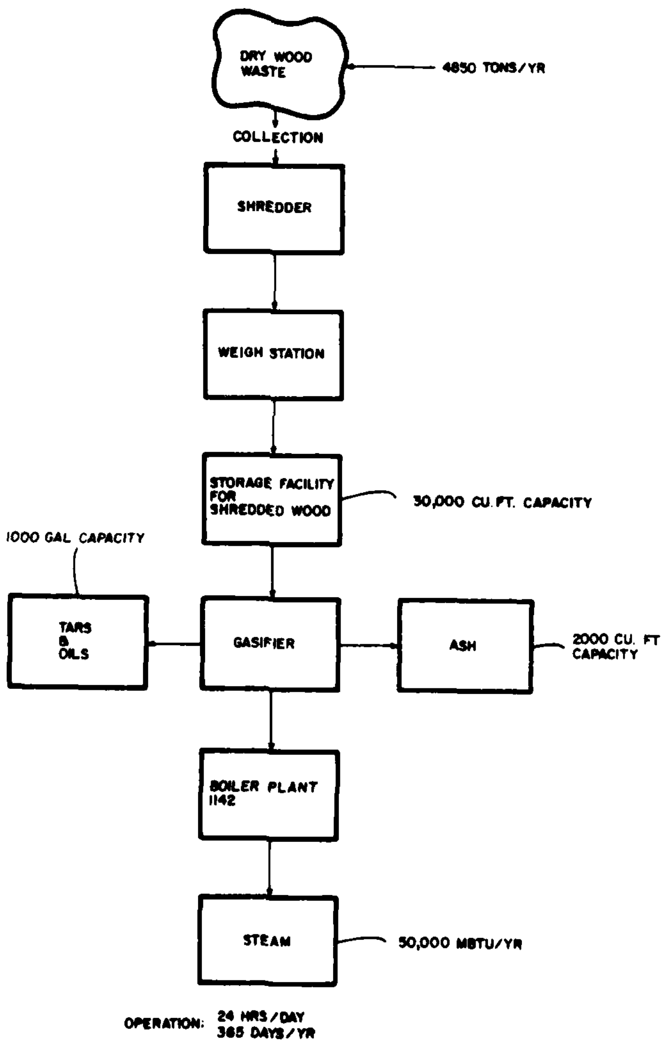

Figure 10. Process flow for Alternative III.

Equipment and Land

The equipment required for Alternative IIIA is the same as that needed for Alternative I; RRAD's shredder can be used to prepare the wood refuse. Other required equipment includes storage facilities for the wood and ash gasifier unit(s), gas cleaning equipment, and conveyors. Alternative IIIB requires the same, except that a gas line and gas cooling and cleaning equipment are not needed.

The auxiliary equipment needed for this alternative is the same as that needed for Alternative I. Figures 11 and 5 show a possible site layout and location for this alternative, respectively.

Cost Analysis

The economic analysis for Alternative IIIA is given in Appendix A, Tables A5 and A6; an FY80 investment of about $1.52 million is required. The 25-year PV saving is about $2.05 million. The SIR is 1.35. Similarly, Alternative IIIB has an FY80 investment of about $945,000, a 25-year PV savings of $2.35 million, and an SIR of 2.48.

Alternative IV

Process Flow

The process flow for Alternative IV is almost the same as for Alternative II, except that shredded dry wood waste is used instead of green wood residue. Figure 12 gives the process flow for Alternative IV. The wood will be weighed on a platform scale before being transferred to the gasifier site, unloaded onto a bucket elevator, and transferred to a storage silo. The conveyor will transfer the wood from the silo to a surge tank where it will be automatically fed into the gasifier. The ash, oils, and tars will be collected and disposed of as described in the discussion of Alternative II. The low-Btu gas will be distributed by pipe to boiler plants 112 and 186.

Equipment and Land

The equipment required for Alternative IV is the same as that needed for Alternative II. However, the fuel stock and shredder will be used instead of a dryer. This will reduce the size required for the storage facility. A schematic of the site and location for Alternative IV is shown in Figures 13 and 5, respectively.

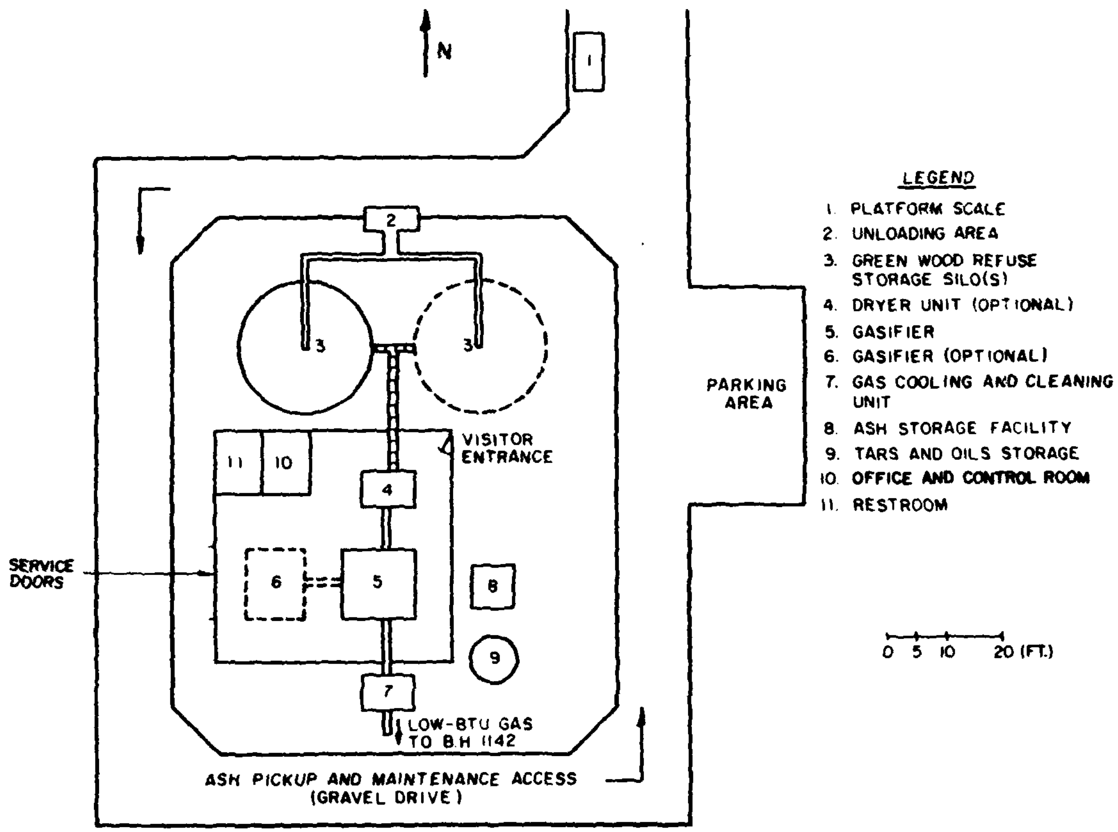

Figure 11. Layout of proposed gasifier site -- Alternative III.

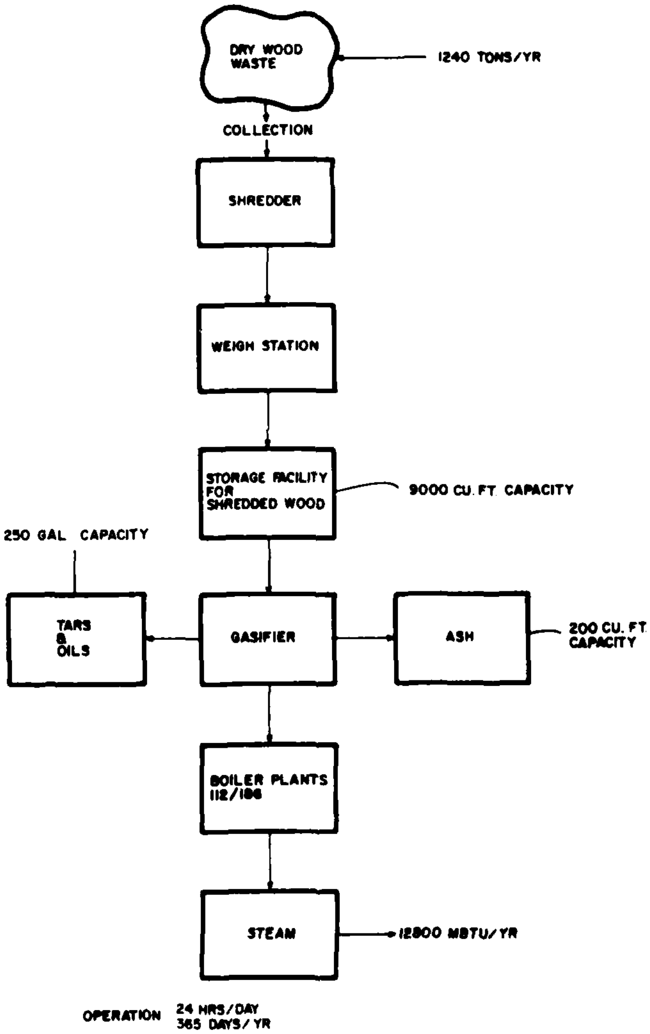

Figure 12. Process flow for Alternative IV.

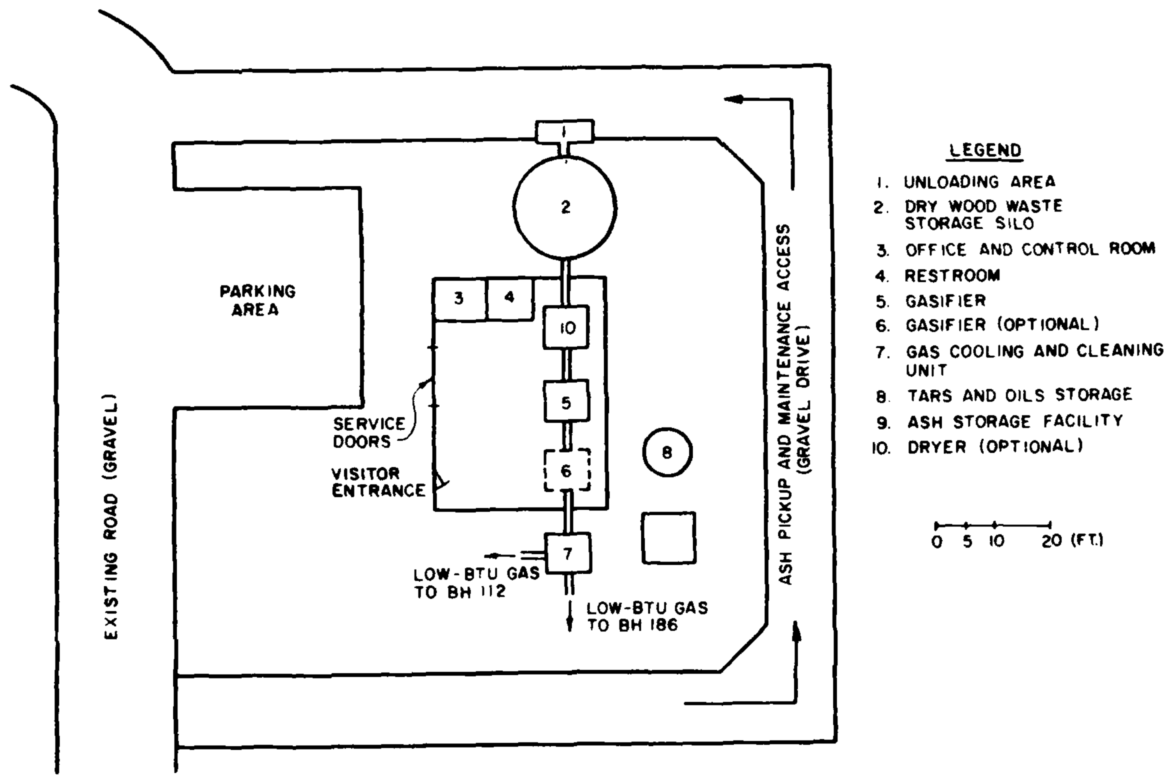

Figure 13. Layout of proposed gasifier site -- Alternative IV.

Cost Analysis

The economic analysis for Alternative IV is given in Appendix A, Tables A7 and A8; an FY80 investment of about $430,000 is required. The 25-year PV saving is about $473,000. The SIR is 0.91.

5 COMPARATIVE ANALYSES OF ALTERNATIVE SYSTEMS

Three analyses were done on the alternative gasifier systems proposed for implementation at RRAD. The first analysis compares the SIRs of the proposed alternative systems. The second looks at the potential amount of natural gas replaced by each proposed alternative. The third is a sensitivity analysis which considers the effect of fuel costs on the SIR.

Comparative Economic Analyses

Table 3 shows the results of the comparative economic analyses done for Alternatives I through IV. SIRs were computed based on cost data for each alternative (see Appendix A). Alternative IIIB had the best SIR of 2.48 and a payback in 6.3 years. The ratio and payback were based on a delivered cost of \$10/ton (\$9/tonne) for dry wood waste.

Potential Natural Gas Replacement

For this analysis, the potential amount of natural gas replaced by each alternative system was determined. Appendix B shows the estimated amount of natural gas replaced and the overall effect on the amount of natural gas consumed at RRAD. Alternatives I and III would each replace 67 million cu ft (1.9×10^6 m^3) of natural gas, or about 15 percent of the natural gas consumed at RRAD.

Sensitivity Analysis

It was assumed that green wood residue and dry wood waste could be delivered to the gasifier units at RRAD at a cost of \$10/ton (\$9/tonne). However, because the actual cost was not known, and because change could occur as market demand fluctuated, a sensitivity analysis was done to determine the effect of varying wood fuel prices.

Figure 14 shows that the effect of wood fuel prices on the SIR of an alternative must be greater than 1.0 to be an economical solution. Alternative I requires that fuel costs be less than \$10.65/ton (\$9.60/tonne) to achieve an SIR greater than 1.0. Alternative IIIA requires that wood fuel costs be less than \$22.04/ton (\$20/tonne) to achieve an SIR greater than 1.0. For Alternative IIIB, fuel costs must be less than \$48.90/ton (\$44.33/tonne) to achieve an SIR greater than 1.0.

For Alternatives II and IV the FY80 capital investment is greater than any 25-year PV savings resulting from replacement of natural gas. This is true for dry wood waste or green wood residue obtained at no cost.

The cost of the wood was considered to be the delivered cost of the chipped (or shredded) wood.

Table 3

Summary of Alternative Systems*

Alternative	Investment FY80 ($)	25-Year PV Savings ($)	SIR**	Years to Payback
I - Boiler plant 1142 (green wood residue)	1592	1645	1.03	22
II - Boiler plants 112 and 186 (green wood residue)	472	363	0.77	>25
IIIA - Boiler plant 1142) dry wood waste), pipeline	1519	2050	1.35	16
IIIB - Boiler plant 1142 (dry wood waste), close-coupled	945	2348	2.48	6.3
IV - Boiler plants 112 and 186, (dry wood waste)	430	473	0.91	>25

*Dollars in thousands, rounded from calculations given in the appendices.
**The SIR was calculated based on the delivered cost of 10/ton(9/tonne) for green wood residue and dry wood waste.

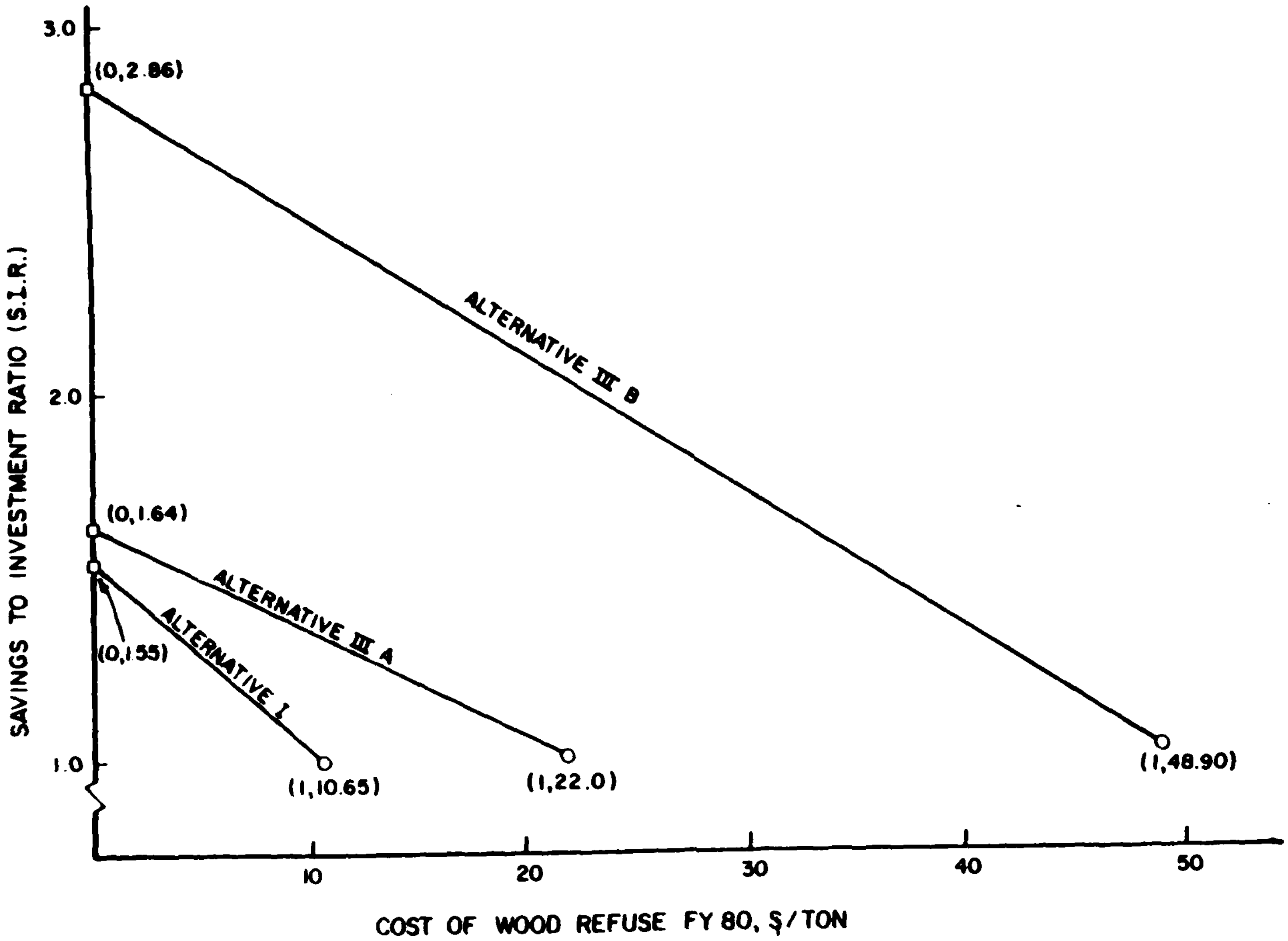

Figure 14. SIR plot of wood waste costs.

6 CONCLUSIONS AND RECOMMENDATIONS

1. Using low-Btu gas as a substitute boiler fuel at RRAD is technically and economically feasible for Alternatives I and III. Alternative IIIB is the most cost-effective alternative. It has an SIR of 2.48 and the potential to replace 67 million standard cu ft (1.9×10^6 m^3) of natural gas annually (15 percent of RRAD's annual consumption). Alternative IIIB (using dry wood waste as feed stock to a gasifier supplying low-Btu gas to boiler plant 1142) should be implemented at RRAD.

2. It has been estimated that there should be enough green wood residue and dry wood waste available at RRAD to meet all alternative fuel requirements. However, if RRAD personnel determine that available wood is insufficient to supply all alternative fuel requirements, it is recommended that a decision concerning which alternative should receive the wood be based both on economics and on the fuel that the wood will replace. Dry wood waste should be considered as fuel stock rather than green wood residue because it has a more favorable SIR.

3. According to gasifier unit manufacturers, local, State, and Federal air pollution standards can be met with available equipment, and the disposal of tars, oils, and ashes will pose no significant technical or environmental problems.

4. Technically feasible gasifer systems are commercially available from manufacturers listed in Appendix C and can be implemented at RRAD. The reliability of the gasifier system installed could be determined on-site by carrying out the demonstration project.

5. To establish capacity and turn-down requirements, recorders should be installed immediately at boiler plants 1142, 112, and 166 to measure daily steam production and natural gas consumption before implementation of any alternatives.

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Retrofit '79: Proceedings of a Workshop on Air Gasification (Solar Energy Research Institute, 2 February 1979).

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Woodyard, John P. and Robert L. Yust, An Evaluation of Installation Scale Technologies for Producing and Using Gaseous and Liquid Fuel from Biomass (SCS Engineers, January 1980).

Technology and Economics of Wood Residue Gasification (Tenth Texas Industrial Wood Seminar, 13 March 1979).

Woodyard, John P. and Robert L. Yust, An Evaluation of Installation Scale Technologies for Producing and Using Gaseous and Liquid Fuel from Biomass (SCS Engineers, January 1980).

APPENDIX A:

COST ANALYSIS OF GASIFIER ALTERNATIVES

This appendix summarizes the capital and annual cost estimates for Alternatives I through IV.

The capital cost estimates for Alternatives I, II, III, and IV are in Tables A1, A2, A3, and A4, respectively. The lists of primary and supporting facility items were obtained from gasifier manufacturers; the 1980 costs for primary facility items are as given by the manufacturer. The 1980 costs for supporting facility items were taken from Army Regulation (AR) 415-17, Empirical Cost Estimates for Military Construction (Department of the Army, August 1978), as are values for location adjustment, cost growth due to technological updating adjustment, engineering, design, supervision, and administration, and cost growth due to economic adjustment. The total capital cost estimate (FY80 dollars) was used for the economic analyses.

Tables A5, A6, A7, and A8 are the operating cost estimates for Alternatives I through IV, respectively. All debits are as given by the manufacturer. The estimated quantity of natural gas replaced was taken from data presented in Appendix B. The 25-year PV multiplying factors were obtained from Department of Energy criteria.[5]

All costs are in FY80 dollars, with the exception of the capital investments, which are in FY83 dollars. (The FY83 dollar capital investment costs are given for program planning purposes.)

[5] Federal Energy Management and Planning Programs: Methodology and Procedures for Life Cycle Cost Analyses, Part IX (Department of Energy, Office of Conservation and Solar Energy, 23 January 1980).

Table A1

Alternative I: Capital Cost Estimate

Description	Quantity	Unit	Unit Cost ($/Unit)	Cost ($)
1. Primary Facility				
Wood chips storage facility	50,000	cu ft	--	100,000
Gasifier unit*	1	each	600,000	600,000
Gas cleaning equipment*	1	each	200,000	200,000
Building	1600	sq ft	35.00	56,000
Boiler modification	1	job	25,000	25,000
Instrumentation and controls	1	job	50,000	50,000
Bucket elevator and conveyor system*	1	each	50,000	50,000
Dryer system*	1	each	50,000	50,000
SUBTOTAL				1,131,000
2. Supporting Facility				
Electrical lines (OH)	1000	linear feet	5.50	5,500
2-in. water distribution lines (UG)	1000	linear feet	6.40	6,400
6-in. sanitary pipe	1000	linear feet	7.60	7,600
10-in. gasline	10,000	linear feet	35.00	350,000
Communications	1	job	5,000	5,000
Site preparation	1	job	5,000	5,000
Landscaping	1	job	5,000	5,000
Fencing	520	linear feet	8.50	4,400
Access road and parking	2000	sq yd	3.72	7,500
SUBTOTAL				396,400
TOTAL EMPIRICAL COST				1,527,400
Location adjustment factor for Texas				x 0.92**
				1,405,210
Cost growth due to technological updating adjustment				x 1.03**
				1,447,360
Engineering, design, supervision, and administration				x 1.10**
TOTAL FY80 DOLLARS (used for economic analysis)				1,592,100
Cost growth due to economic factors adjustment				x 1.20**
TOTAL (FY83 Dollars)				1,910,520

*These items are used to compute maintenance debits in Table A5.
**From Empirical Cost Estimates for Military Construction, AR 415-17 (Department of the Army, August 1978).

Table A2

Alternative II: Capital Cost Estimate

Description	Quantity	Unit	Unit Cost ($/Unit)	Costs ($)
1. Primary Facility				
Wood chips storage facility	14,000	cu ft	-	30,000
Gasifier unit*	1	each	110,000	110,000
Gas cleaning equipment*	1	each	100,000	100,000
Building	1,200	sq ft	35.00	42,000
Boiler modification	1	job	15,000	15,000
Instrumentation and controls	1	job	25,000	25,000
Bucket elevator and conveyor system*	1	each	30,000	30,000
Dryer system*	1	each	20,000	20,000
SUBTOTAL				372,000
2. Supporting Facility				
Electrical lines (OH)	500	linear feet	5.45	2,700
2-in. water distribution lines (UG)	500	linear feet	6.35	3,200
6-in. sanitary pipe	500	linear feet	7.60	3,800
8-in. gasline	1600	linear feet	35.00	56,000
Communications	1	job	5,000	5,000
Site preparation	1	job	2,000	2,000
Landscaping	1	job	2,000	2,000
Fencing	240	linear feet	8.50	2,000
Access road and parking	1000	sq yd	3.72	3,700
SUBTOTAL				80,400
TOTAL EMPIRICAL COST				452,400
Location adjustment for Texas				x0.92**
				416,210
Cost growth due to technological updating adjustment				x1.03**
				428,690
Engineering, design, supervision, and administration				x1.10**
TOTAL FY80 DOLLARS (used for economic analysis)				471,560
Cost growth due to economic factors adjustment				x1.20**
TOTAL (FY83 Dollars)				565,880

*These items are used to calculate maintenance debits in Table A6.
**From Empirical Cost Estimates for Military Construction, AR 415-17 (Department of the Army, August 1978).

Table A3

Alternative III: Capital Cost Estimate

Description	Quantity	Unit	Unit Cost ($/Unit)	(Cost ($)
1. Primary Facility				
Shredded wood storage facility	30,000	cu ft	--	80,000
Gasifier unit*	1	each	600,000	600,000
Gas cleaning equipment*,**	1	each	200,000	200,000
Building	1,600	sq ft	35.00	56,000
Boiler modification	1	job	25,000	25,000
Instrumentation and controls	1	job	50,000	50,000
Bucket elevator and conveyor system*	1	each	50,000	50,000
SUBTOTAL				1,061,000
2. Supporting Facility				
Electrical lines (OH)	1,000	linear feet	5.50	5,500
2-in. water distribution lines	1,000	linear feet	6.40	6,400
6-in. sanitary pipe	1,000	linear feet	7.60	7,600
10-in. gas line**	10,000	linear feet	35.00	350,000
Communications	1	job	5,000	5,000
Site preparation	1	job	5,000	5,000
Landscaping	1	job	5,000	5,000
Fencing	520	linear feet	8.50	4,400
Access road and parking	2,000	sq yd	3.72	7,500
SUBTOTAL				396,400
TOTAL EMPIRICAL COST				1,457,400
Location adjustment factor for Texas				x 0.92***
				1,340,810
Cost growth due to technological updating adjustment				x 1.03***
				1,381,030
Engineering, design, supervision, and administration				x 1.10***
TOTAL FY80 DOLLARS (used for economic analysis)**				1,519,140
Cost growth due to economic factors adjustment				x 1.20***
TOTAL (FY83 Dollars)				1,822,960

*These items are used to calculate maintenance debits in Table A7.
**The FY80 investment costs for Alternative IIIB are $945,837. This investment is determined by subtracting out all items so identified.
***From *Empirical Cost Estimates For Military Construction*, AR 415-17 (Department of the Army, August 1978).

Table A4

Alternative IV: Capital Cost Estimate

Description	Quantity	Unit	Unit Cost ($/Unit)	Cost ($)
1. Primary Facility				
Shredded wood storage facility	9,000	cu ft	--	20,000
Gasifier unit*	1	each	110,000	110,000
Gas cleaning equipment*	1	each	100,000	100,000
Building	1,200	sq ft	35.00	42,000
Boiler modification	1	job	15,000	15,000
Instrumentation and controls	1	job	25,000	25,000
Bucket elevator and conveyor system*	1	each	20,000	20,000
SUBTOTAL				332,000
2. Supporting Facility				
Electrical lines (OH)	500	linear feet	5.45	2,700
2-in. water distribution lines	500	linear feet	6.35	3,200
6-in. sanitary pipe	500	linear feet	7.60	3,800
8-in. gasline	1,600	linear feet	35.00	56,000
Communications	1	job	5,000	5,000
Site preparation	1	job	2,000	2,000
Landscaping	1	job	2,000	2,000
Fencing	240	linear feet	8.50	2,000
Access road and parking	1000	sq yd	3.72	3,700
SUBTOTAL				80,400
TOTAL EMPIRICAL COST				412,400
Location adjustment factor for Texas				x 0.92**
				379,410
Cost growth due to technological updating adjustment				x 1.03**
				390,790
Engineering design supervision and administration				x 1.10**
TOTAL FY80 DOLLARS (used for economic analysis)				429,870
Cost growth due to economic factors adjustment				x 1.20**
TOTAL (FY83 Dollars)				515,840

*These items are used to calculate maintenance debits in Table A8.
**From Empirical Cost Estimates for Military Construction, AR 415-17 (Department of the Army, August 1978).

Table A5

Alternative I: Annual Cost Estimates

Item	Quantity	Unit	Unit Cost ($/Unit)	Annual Cost FY80 ($)	PV 25-Year Multiplier Factor	PV 25-Year Costs ($)
1. Debits						
Gasifier operator	2080	manhour	9.39	19,531	9.08	177,343
Ash disposal	100	tons	8.45	845	9.08	7,672
Maintenance	(4% of items in Table A1)			36,000	9.08	326,880
Electricity	500,000	kWh	0.022	11,000	11.6	127,600
Water and sewer	1400	kgal	1.0	1,400	9.08	12,712
Wood chips (50% moisture content)	9100*	tons	10.0	91,000	9.08	826,280
TOTAL DEBITS				159,776		1,478,487
2. Credits						
Natural gas	67,000	MBtu	3.49	233,830	13.36	3,123,969
TOTAL CREDITS				233,830		3,123,969
Cost Estimate				-74,054**		-1,645,482**,***

*Data from Appendix B.
**A minus (-) cost is a saving or credit.
***The $-1,645,482 represents an operational savings over a 25-year economic life of the alternative.

Table A6

Alternative II: Annual Cost Estimates

Item	Quantity	Unit	Unit Cost ($/Unit)	Annual Cost FY80 ($)	PV 25-Year Multiplier Factor	PV 25-Year Costs ($)
1. Debits						
Gasifier operator	1040	manhour	9.39	9,765	9.08	88,666
Ash disposal	20	tons	8.45	170.0	9.08	1,543
Maintenance	(4% of items in Table A2)			10,400	9.08	94,432
Electricity	150,000	kWh	0.022	3300	11.6	38,280
Water and sewer	280	kgal	1.0	280	9.08	2,542
Green wood (50% moisture content)*	2340	tons	10.0	23,400	9.08	212,472
TOTAL DEBITS				47,315		437,935
2. Credits						
Natural gas	17,172	MBtu	3.49	59,930	13.36	800,665
TOTAL CREDITS				59,930		800,665
Cost Estimate				-12,615**		-362,730**

*Data from Appendix B.
**A minus (-) cost is a saving or credit.

Table A7

Alternative III: Annual Cost Estimates

Item	Quantity	Unit	Unit Cost ($/Unit)	Annual Cost FY80 ($)	PV 25-Year Multiplier Factor	PV 25-Year (Costs) ($)
1. Debits						
Gasifier operator	2,080	manhour	9.39	19,531	9.08	177,341
Ash disposal	100	tons	8.45	845	9.08	7,672
Maintenance	(4% of items in Table A3)		-	34,000	9.08	308,720
Electricity	500,000	kWh	0.022	11,000	11.6	127,600
Water and sewer	1,400	kgal	1.0	1,400	9.08	12,712
Dry wood refuse (10% moisture* content)	4,850	tons	10.0	48,500	9.08	440,380
TOTAL DEBITS				104,276		1,074,425
2. Credits						
Natural gas	67,000	MBtu	3.49	233,830	13.36	3,123,969
TOTAL CREDITS				233,830		3,123,969
Cost estimate***				-129,554**		-2,049,544**

*Data from Appendix B.
**A minus (-) cost is a saving or credit.
***The 25-year PV estimate for Alternative IIIB is $2,347,962. The annual savings is $150,137.

Table A8

Alternative IV: Annual Cost Estimates

Item	Quantity	Unit	Unit Cost ($/Unit)	Annual Cost FY80 ($)	PV 25-Year Multiplier Factor	PV 25-Year Costs ($)
1. *Debits*						
Gasifier operator	1,040	manhour	9.39	9,765	9.08	88,666
Ash disposal	20	tons	8.45	170	9.08	1,543
Maintenance	(4% of items in Table A4)			9,200	9.08	83,536
Electricity	150,000	kWh	0.022	3,300	11.6	38,280
Water and sewer	280	kgal	1.0	280	9.08	2,542
Dry wood refuse (10% moisture content)*	1,250	tons	10.0	12,500	9.08	113,500
TOTAL DEBITS				35,215		328,067
2. Credits						
Natural gas	17,172	MBtu	3.49	59,930	13.36	800,665
TOTAL CREDITS				59,930		800,665
Cost Estimate				-24,715**		-472,598**

*Data from Appendix B.
**A minus (-) cost is a saving or a credit.

APPENDIX B:

DETERMINATION OF WOOD REFUSE REQUIRED AS FEEDSTOCK FOR GASIFIERS AT BOILER PLANTS 1142, 112, and 186

The calculations in this appendix determine the amount of energy required for each candidate boiler plant. This is done by (1) estimating the amount of energy in available wood refuse, and (2) determining the load requirements at each boiler plant.

The following equations* and assumptions were used to estimate the energy available in wood refuse:

$$HHV = 9152\ (1 - MC_{WB}) \qquad \text{[Eq B1]}$$

$$LHV = HHV - 1000\ \frac{\text{Btu}}{\text{lb}}\ (MC_{WB}) \qquad \text{[Eq B2]}$$

$$LHV\ (\text{dry wood waste - 15\% MC}) = 15.3\ \text{MBtu/ton} \qquad \text{[Eq B3]}$$

$$LHV\ (\text{green wood residue - 50\% MC}) = 8.15\ \text{MBtu/ton} \qquad \text{[Eq B4]}$$

where:

HHV is the higher heating value
LHV is the lower heating value
MC is the moisture content of the waste or residue
MC_{WB} is the moisture content determined on a wet basis.

The following assumptions were made to estimate the energy requirements of each candidate boiler plant:

Boiler efficiencies = 75 percent

Boiler derating** = 10 percent (for "cold" low-Btu gas applications)

Btu/lb of steam = 1000 Btu/lb (2.3×10^6 J/kg)

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* Metric equivalents: 1 MBtu = 1.05×10^9 J; 1 lb = 0.45 kg; 1 MBtu/lb = 2.326 $\times 10^9$ J/kg; 1 MBtu/year = 1.05 x 10 J/year; and 1 ton = 0.907 tonne.
**Boiler derating = 3 percent (for "hot" low-Btu gas applications).

Boiler Plant 1142

Designed boiler output - 31,000 $\frac{lb}{hr}$ = 272,000 MBtu/yr (100% operation 8760 hr/year)

Estimated boiler output = 50,000 MBtu/year*

Estimated boiler input = $\frac{(50,000\ \text{MBtu/year})}{0.75}$ = 67,000 MBtu/year (natural gas equivalent)

Estimated boiler input = $\frac{(50,000\ \text{MBtu/year})}{(0.75)\ (0.90)\ (15.3\ \text{MBtu/ton})}$

= 4850 $\frac{ton}{year}$ (dry wood equivalent; 15% MC)**

Estimated boiler input = $\frac{50,000\ \text{MBtu/year}}{(0.75)\ (0.90)\ (8.15\ \text{MBtu/ton})}$ = 9,100 tons (green wood equivalent)

Boiler Plants 112 and 186

Designed boiler output - 8140 $\frac{lb}{hr}$ = 71,300 $\frac{MBtu}{year}$ (100% operation; 8760 hr/year)

Estimated boiler output = 12,800 MBtu/year

Estimated boiler input = $\frac{(12,800)}{0.75}$ = 17,172 MBtu/year (natural gas equivalent)

Estimated boiler input = $\frac{(12,800)}{(0.75)\ (0.90)\ (015.3)}$ = 1240 tons/year

(dry wood equivalent; 15% MC)

Estimated boiler input = $\frac{(12,800)}{(0.75)\ (0.90)\ (8.15)}$ = 2340 tons/year

(green wood equivalent; 50% MC)

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* Based on steam data, CY79 (see Table 1).
Based on the boiler plant 1142 profile or 18 percent of designed boiler output due to variations in load required over a 1-year period.

APPENDIX C:

BIOMASS GASIFICATION EQUIPMENT MANUFACTURERS

ANDCO, INC.
25 Anderson Road
Checktowaga, NY
(716) 896-8181
Mr. Stan Mark

APPLIED ENGINEERING CO.
Box 1337
Orangeburg, SC 29115
(803) 534-2424
Mr. Dean Harris

DUVANT MOTEURS
Old Country Road
Carle Place, NY 11514
(516) 248-0880
Mr. George Bonnici

ENERGY RESOURCES CO., INC.
185 Alewife Brk. Parkway
Cambridge, MA
(617) 661-3111
Mr. John Sims

FOREST FUELS, INC.
7 Main Street
Keene, NH 03431
(603) 357-3311
Mr. Martin Stevens

NICHOLS ENGINEERING AND
RESEARCH CORP.
Homestead and Willow Road
Belle Mead, NJ 08502
(201) 359-8200
Mr. William Threthaway
Mr. Richard Shedlow

ENVIRONMENTAL ENERGY
ENGINEERING, INC.
P. O. Box 4214
(304) 328-5116
Dr. Richard Bailie

ALTERNATIVE ENERGY COMPANY
4800 Manzanita Avenue, Suite 13
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(916) 483-2761, 448-2000
Mr. Jack Cunningham IV

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Uba City, CA
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Mr. Ted Crane

ENERGY RECOVERY RESEARCH GROUP, INC.
3420 Ocean Park Boulevard
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Santa Monica, CA 90405
(213) 450-5679
Mr. Philip Junkins

ALBERTA INDUSTRIAL DEVELOPMENTS, LTD
704 Cambridge Building
Edmonton, Alberta
Canada T5J 1R9

APPLIED ENGINEERING COMPANY
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Orangeburg, SC 29115
(803) 534-2424

CENTURY RESEARCH, INC.
16935 S. Vermont Avenue
Gardens, CA 90247
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HALCYON ASSOCIATES, INC.
Maple Street
East Andoven, NH 03231
(603) 735-5356

DAVY POWERGAS, INC.
P. O. Box 3644
Houston, TX 77036
(713) 782-3440

AMERICAN FYR-FEEDER
1265 Rand Road
Des Plaines, IL 60615
(312) 298-0044
Mr. Gauger

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APPENDIX D:

ENVIRONMENTAL ASSESSMENT -- SUMMARY

Biomass conversion processes fall into two major classes: thermochemical and biochemical. Wood gasification falls under the thermochemical process which produces gaseous emissions that have a significantly less severe environmental impact than coal or petroleum emissions, but they still produce human health and environmental problems. The air emissions include particulates, oxides of nitrogen, sulfur, and carbon, hydrogen cyanide, ammonia, and hydrocarbons. There are a number of procedures available for controlling these pollutants. Water quality from gasification processes can be impaired by oils, phenols, and polycyclic aromatic hydrocarbons. Liquid waste streams from the gasification reaction contain high levels of biochemical oxygen demand (BOD) phenols, oils, and refractory materials that require treatment prior to final discharge. Ash residue from gasification requires proper disposal techniques to avoid leaching of pollutants into water supply aquifers or surface stream/lake. Air pollution emissions may originate from process stacks, waste ponds, storage tanks, equipment leaks, and storage piles. Pollutants of concern include oxides of nitrogen, hydrogen, sulfur, hydrocarbons, ammonia, and to a lesser extent, carbon monoxide and particulates. Many of the same pollutants will also be found in process water and condensates. In addition, phenols, trace metals and leachates from biomass storage piles, char, and ash residues may contribute to the degradation of water quality.

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